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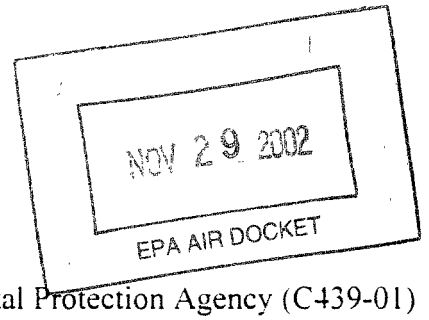

MEMORANDUM

TO: Jim Eddinger, U.S. Environmental Protection Agency (C439-01)

FROM: Chad Leatherwood, Eastern Research Group

DATE: October, 2002

SUBJECT: Development of Fuel Switching Costs and Emission Reductions for Industrial/Commercial/Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants

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1.0 INTRODUCTION

The purpose of this memorandum is to discuss the cost and emission impacts resulting from fuel switching in boilers and process heaters. Fuel switching is a potential control option that would require some boilers and process heaters to convert to natural gas, which emits lower emissions of some compounds when combusted than most solid and liquid fuels such as coal and residual oil. For many pollutants, fuel switching generally results in greater emission reductions than add-on technologies, and for some pollutants, fuel switching may be the only control method available.

For this analysis, the cost, emission, and operational impacts of fuel switching coal-fired and residual oil-fired boilers and process heaters to natural gas were examined. It was assumed that units burning biomass, non-fossil fuel, or wood, alone or in combination with gaseous fuel, would be unlikely to fuel switch to natural gas alone. This assumption is based on the availability of the current fuel blend, the cost differential between the current fuel blend and natural gas, and the limited emission reductions that would be achieved over add-on control devices. Similarly, it was assumed that units burning distillate oil would not fuel switch because of the limited emission reduction that would be achieved.

Section 2.0 summarizes the results of the analysis. Section 3.0 discusses the analysis in more detail, and Section 4.0 presents references. Detailed calculation tables are in Attachment A.

2.0 RESULTS OF ANALYSIS

Table 2-1 summarizes the capital investment and annual costs estimated for fuel switching coal-fired and residual oil-fired boilers and process heaters to natural gas. Fuel switching would require over $3 billion in capital costs and $12 billion in annual costs. Of these totals, units firing coal, either wholly or partially, incur 66 percent of the capital and 83 percent of the annual costs. Additionally, 93 percent of the capital and 94 percent of the annual costs are from fuel switching boilers.

Table 2-1. Summary of Capital and Annual Costs for Fuel Switching to Natural Gas

	Fuel	Capital Costs ($ 1,000,000)	Annual Costs ($1,000,000/yr)
Boilers	Coal	2,092	10,644
	Residual Oil	868	1,383
	Total	2,960	12,026
Process Heaters	Coal	0	0
	Residual Oil	215	826
	Total	215	826
Total	Coal	2,092	10,644
	Residual Oil	1,083	2,208
	Total	3,175	12,851

Table 2-2 summarizes the emission reductions for selected pollutants as a result of fuel switching. Emissions of metallic, inorganic, and some organic compounds decrease as a result of fuel switching. However, emissions of some organic compounds, such as formaldehyde, would increase with fuel switching.

Table 2-2. Summary of Emission Reductions of Selected Compounds from Fuel Switching (Mg/yr)

Combustor	Fuel	Metals					Acid Gases		Organics			
		Arsenic	Chromium	Lead	Manganese	Mercury	Hydrogen Chloride	Hydrogen Fluoride	Acetaldehyde	Benzene	Formaldehyde	Toluene
Boilers	Coal	70	77	100	432	6.1	53,216	4,583	-64	505	211	16
	Residual Oil	2	11	5.8	510	3.4	22	0	-100	3.0	-79	14
	Total	72	88	106	943	9.5	53,238	4,583	-164	508	132	30
Process Heaters	Coal	0	0	0	0	0	0	0	0	0	0	0
	Residual Oil	0.5	2.7	1.4	126	0.8	5.3	0	-23	0.7	-19	3.3
	Total	0.5	2.7	1.4	126	0.8	5.3	0	-23	0.7	-19	3.3
Total	Coal	70	77	100	432	6.1	53,216	4,583	-64	505	211	16
	Residual Oil	2.5	14	7.2	636	4.2	27	0	-123	3.7	-98	17
	Total	73	91	107	1,069	10	53,243	4,583	-187	509	113	33

3.0 DESCRIPTION OF ANALYSIS

3.1 Background

A portion of the work products developed by the Industrial Combustion Coordinated Rulemaking (ICCR) Federal Advisory Committee Act were databases that contained an inventory of the population of boilers, process heaters, IC engines, turbines, and incinerators in the nation. Detailed information about these databases can be found in other memoranda.[1-5]

A review of the population databases indicated that each boiler or process heater (that does not solely burn natural gas) could be categorized into three scenarios involving fuel switching to natural gas.

A. The boiler or process heater already uses natural gas as a start-up or back-up fuel. Therefore, it would only require modifications to the boiler or process heater to burn natural gas only.

B. The boiler or process heater does not use natural gas as a start-up or back-up fuel, but the facility does use gas for some operation on site. This would require modifications to the boiler or process heater and upgrades to the on-site gas handling system.

C. The facility does not use natural gas at all. This would require modifications to the boiler or process heater, construction of an on-site gas handling system, and construction of piping from the most accessible main gas line.

Additionally, Scenario C was further divided into four cases to address the potential availability of natural gas for boilers and process heaters.

C1: The main gas line is close to the plant, but the plant is in a city or near a city. Therefore, a higher cost per foot of pipe would be incurred.

C2: The main gas line is a moderate distance from the plant, and the plant is in a rural location. A lower cost per foot of pipe would be incurred.

C3: The main gas line is far from the plant, and the plant is in a rural location. A lower cost per foot of pipe would be incurred.

C4: Gas is not available at all.

Each boiler and process heater in the population database was assigned to one of the above scenarios/cases.

3.2 Assignment of Boilers and Process Heaters to Fuel Switching Scenarios

The ICCR population database for boiler and process heaters identify whether a unit already co-fires natural gas. Those that do were assigned to Scenario A. Any boiler or process heater not identified as firing natural gas, but located at a facility that does have another combustion unit firing natural gas was assigned to Scenario B. It was assumed that a natural gas line was available at the facility, so costs incurred for fuel switching the boiler or process heater would be for modification of the on-site gas handling system and for boiler or process heater combustor modifications.

Model units were used to represent the national population of boilers and process heaters. Boilers and process heaters were assigned to models based on the fuel burned, capacity, and combustor type. A detailed discussion of model units is presented in another memorandum.[6] Capacity data were not available for all boilers and process heaters, so units with unknown capacities were assigned to models based on fuel and combustor type using the same distribution (i.e., relative percentages of population) as that for units with known capacities. Attachments A-1 and A-2 present the distribution of boilers and process heaters to Scenarios A and B.

Scenario C units were assumed to be all the boilers and process heaters that were not assigned to scenarios A or B. The boiler and process heaters databases do not provide any information that could be used to assign units to the Scenario C cases. It was assumed that the majority of Case C units would be in case C2 because the widespread use of natural gas lines.[7] To provide a conservative estimate of costs, the majority of the remaining units were assumed to be in case C3, then C1. It was also assumed than only a very small number of boilers and process heaters would not have gas available at all, case C4. For this analysis, case C units were distributed in the following percentages: C1=5%, C2= 84%, C3 = 10%, and C4=1%.

3.3 Development of Cost Inputs and Factors

Costs were estimated using 1997 as the base year. Information used to calculate capital and annual costs for fuel switching were obtained from two sources: (1) a feasibility study from 1986 on converting oil- and coal-fired utility boilers to fire gas intermittently[8], and (2) a Phase II

NOx control report.[9] The equations used to calculate capital and annual costs are provided in Attachment A-3. Costing inputs are summarized in Attachment A-4.

Capital Costs. The 1986 feasibility study provided detailed capital cost breakdowns, in dollars per kilowatt of capacity ($/kW), for fuel switching to natural gas for five utility boilers at five different sites. For this analysis, it was assumed that capital costs for intermittent use of natural gas at utility boilers could be used for continuous use of natural gas by industrial/institutional/commercial boilers and process heaters. Attachment A-5 presents the cost components from the 1986 document. The attachment lists the costs of each component from the five studies found in the 1986 feasibility study. For the five utility boilers studied, different breakdowns, component groupings, and component names were used. Similar components were grouped together based on descriptions provided and engineering judgment. The table also allocates components to either the gas handling system, combustor system, or "other" (administrative, vendor representative, startup, etc).

Attachment A-6 presents the costs calculated for each scenario. Components were assigned to scenarios A and B using engineering judgment based on the costs that would probably be incurred for each scenario. The average costs for gas systems or combustor systems were calculated for each case and added to the "other" costs to obtain the total cost of fuel switching for each case. Average costs were used to account for differences between the studies and to provide a normalized cost factor. It was assumed that each case would require "other" costs. Costs were escalated from 1985 dollars to 1997 dollars using the Chemical Engineering plant cost indices.[10]

For the scenario C cases C1, C2, and C3, the only additional costs beyond those for Case B are the costs for the piping and piping installation (e.g., Case C1 cost = Scenario B cost + Case C1 piping cost). For this analysis, the pipe lengths used in cost estimates were 500 feet for case C1, 1 mile for case C2, and 10 miles for case C3. Pipe lengths were based on engineering judgment, information provided in the feasibility study, and a study of pipelines in the United States.[7] The cost per foot of pipe was determined based on whether the scenario would be in a city or a rural area. Using information in the feasibility study, a cost of $125 per foot of pipe was used for pipelines in a city (case C1) and a cost of $25 per foot of pipe was used for pipelines in a rural location (cases C1 and C2). The higher cost for city pipelines are due to greater

construction costs to install pipelines in smaller, more congested areas. For case C4, because gas is not available, the cost of add-on controls was used. The cost of add-on controls is discussed in another memorandum.[11]

Total Annual Costs. The components of total annual costs for fuel switching that apply to industrial boilers and process heaters include:

- Annualized capital
- Difference in fuel costs between natural gas and current fuel blend
- Efficiency loss due to fuel switching
- SO_2 Allowances
- Capacity recovery

SO_2 allowances and capacity recovery were not included in the analysis because there was insufficient information to estimate them. Additionally, they are not considered to be as significant as the annualized capital costs and annual fuel cost differences, and their exclusion should not have a significant impact on the results of the analysis. Annualized capital costs were estimated using an interest rate of 7 percent and assuming that the fuel switching equipment has a 20-year life span (equal to a capital recovery factor (CRF) of 0.09439). The 7 percent interest rate is the current rate used in EPA analyses.

Differences in fuel costs were calculated based on the prices obtained from the Department of Energy (DOE) Energy Information Administration (EIA) database for 1997[12], and converted to a dollars per million Btu ($/MMBtu) basis:

Coal cost	=	$35.72/metric ton = $1.35/MMBtu assuming 12,000 Btu per lb heating value[13]
Gas cost	=	$3.59/thousand standard cubic feet = $3.52/MMBtu assuming 1,020 Btu per scf heating value[13]
Residual Oil cost	=	$2.90/MMBtu

For this analysis, it was also assumed that each unit would operate 8,400 hours per year (i.e., two weeks down time per year).

The 1986 feasibility study provides an average efficiency loss of 5 percent when converting to natural gas. This value was used to calculate the additional heat input required to overcome the loss. The equations used to calculate capital and annual costs are provided in Attachment A-3. Costing inputs are summarized in Attachment A-4.

3.4 Calculation of Cost Impacts

Capital and annual costs of fuel switching all of the boilers and process heaters assigned to each applicable model unit (i.e. coal or residual oil-fired models) are presented in Attachment A-7. For this analysis, it was assumed that models co-firing any amount of coal would completely fuel switch to natural gas instead of replacing coal with another fuel. This provides a conservative cost estimate of costs from these models. More detailed calculation tables are found in Attachments A-8 and A-9. Attachments A-10 and A-11 present the calculation of Scenario C capital costs assuming inputs for cost of pipe, length of pipe, and percentage of model units that comprise each case. Attachment A-12 compares the costs of fuel switching to the costs of add-on control technologies for each model.

3.5 Calculation of Emission Impacts

Attachments A-13 and A-14 present the emission reductions for selected compounds from fuel switching for each boiler and process heater model, respectively. Emission reductions from fuel switching were calculated by subtracting emissions estimated from burning natural gas from emissions estimated from burning the existing fuel(s). Emissions from combusting the existing fuel were calculated for the baseline emissions analysis and are discussed in another memorandum.[14] Emissions from using natural gas only were calculated using emission factors developed for the baseline emissions analysis. Emission factors for natural gas combustion are discussed in detail in another memorandum.[14] As stated in Section 2.0, emissions for most pollutants are reduced by fuel switching. However, for some organic compounds that are present in larger quantities in natural gas than coal, such as acetaldehyde and formaldehyde, increases in emissions (represented by a negative number) were predicted. Attachment A-15 compares the fuel switching emission reductions to reductions achieved using add-on control technologies.

4.0 REFERENCES

1. Stephanie Finn and Jason Huckaby, ERG. Memorandum to Fred Porter, Bill Maxwell, and Jim Eddinger, EPA/ESD/CG. *Development of the ICCR Inventory Database, Versions 4.0 and 4.1.* September 9, 1999.

2. Stephanie Finn and Linda Fuller, ERG. Memorandum to Fred Porter and Jim Eddinger, U.S. Environmental Protection Agency. *Data Entry and Quality Assurance Process in the Formation of ICCR Survey Database 3.0.* September 13, 1999.

3. Jeanette Alvis, ERG. Memorandum to Bill Maxwell and Fred Porter, U.S. Environmental Protection Agency, OAQPS. *Description of the ICCR Inventory Database , Versions 4.0 and 4.1.* September 3, 1999.

4. David Rhodes, ERG. Memorandum to Fred Porter and Jim Eddinger, U.S. Environmental Protection Agency. *Description of Fields in the ICCR Survey Database Version 3.0.* September 8, 1999.

5. Jeanette Alvis and Christy Burlew, ERG. Memorandum to Jim Eddinger, U.S. Environmental Protection Agency, OAQPS. *Development of the Population Database for the Industrial/Commercial/Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants.* October, 2002.

6. Jeanette Alvis, Christy Burlew, and Roy Oommen, ERG. Memorandum to Jim Eddinger, U.S. Environmental Protection Agency, OAQPS. *Development of Model Units for the Industrial/Commercial/Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants.* October, 2002.

7. Capacity and Service on the Interstate Natural Gas Pipeline System 1990, Regional Profiles and Analyses. Department of Energy Information Administration. June, 1992. DOE/EIA-0556.

8. Feasibility and Cost of Converting Oil- and Coal-fired Utility Boilers to Intermittent Use of Natural Gas, Fay, James A., et al., Massachusetts Institute of Technology, December 1986.

9. Phase II NOx Controls for the MARAMA and NESCAUM Regions, EPA-453/R-96-002, November 1995

10. Chemical Engineering. January 1999. Economic Indicators, p. 154.

11. Roy Oommen, ERG. Memorandum to Jim Eddinger, U.S. Environmental Protection Agency, OAQPS. *Methodology for Estimating Control Costs for the Industrial/Commercial/Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants.* October, 2002.

12. Annual Energy Outlook 1999. Energy Information Administration. December 1998. DOE/EIA-0383 (99).

13. Compilation of Air Pollution Emission Factors (AP-42), Volume 1: Stationary Point and Area Sources, Fifth Edition. Office of Air Quality Planning and Standards, RTP, North Carolina. January 1995. Appendix A, p. A-5.

14. Christy Burlew, ERG. Memorandum to Jim Eddinger, U.S. Environmental Protection Agency, OAQPS. *Development of Average Emission Factors and Baseline Emissions Estimates for the Industrial, Commercial, and Institutional Boilers and Process Heaters National Emission Standards for Hazardous Air Pollutants.* October, 2002.

APPENDIX A

Detailed Cost and Emission Reduction Tables

(See Excel spreadsheet "Fswitchappa.xls")

Appendix A-1. Distribution of Model Boiler Units Between Fuel Switching Scenarios A,B, and C

Model Parameters (Capacity in MMBtu/hr)						Known		Assumed		Total		
Model No	Material	Combustor Type	Capacity Range	Avg Capacity	Final # of Units	Case A	Case B	Boilers w/o Capacity Data distributed into Model - Case A	Boilers w/o Capacity Data distributed into Model - Case B	Case A	Case B	Case C
1	Coal	Other	0-10	4	83	2	5	3	8	5	13	64
2	Coal	Other	10-100	54	919	87	164	105	197	192	361	366
3	Coal	Other	100-250	166	509	54	100	60	110	114	210	185
4	Coal	Other	>250	565	204	25	16	25	16	50	32	122
5	Coal	Wall-fired/PC	0-10	2	12	1	2	1	3	2	5	5
6	Coal	Wall-fired/PC	10-100	57	98	25	6	33	8	58	14	26
7	Coal	Wall-fired/PC	100-250	186	212	29	35	39	47	68	82	63
8	Coal	Wall-fired/PC	>250	600	291	48	32	66	44	114	76	100
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	7	0	1	0	0	0	1	6
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	67	8	4	0	0	8	4	55
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	18	4	9	0	1	4	10	4
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	77	31	19	1	1	32	20	26
40	Residual Liquid FF	All	0-10	3	477	16	27	32	55	48	82	347
41	Residual Liquid FF	All	10-100	37	1,154	50	81	79	129	129	210	815
42	Residual Liquid FF	All	100-250	172	264	31	37	40	48	71	85	108
43	Residual Liquid FF	All	>250	547	141	19	17	25	22	44	39	58
47	Coal	Other	0-10	4	36	0	0	0	0	0	0	36
48	Coal	Other	10-100	54	70	2	19	3	29	5	48	18
49	Coal	Other	100-250	466	29	1	5	2	11	3	16	10
50	Coal	Other	>250	565	7	2	0	2	0	4	0	4
52	Coal	Wall-fired/PC	10-100	57	32	1	5	4	18	5	23	5
53	Coal	Wall-fired/PC	100-250	186	9	0	0	0	0	0	0	9
54	Coal	Wall-fired/PC	>250	600	15	4	0	8	0	12	0	3
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	1	0	0	0	0	0	0	1
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	2	0	0	0	0	0	0	2
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	1	0	0	0	0	0	0	1
80	Residual Liquid FF	All	0-10	3	159	9	10	33	37	42	47	70
81	Residual Liquid FF	All	10-100	37	304	60	16	124	33	184	49	71
82	Residual Liquid FF	All	100-250	172	63	5	8	12	19	17	27	20
83	Residual Liquid FF	All	>250	547	7	2	0	5	0	7	0	0
	TOTAL				**5,268**	**516**	**618**	**703**	**834**	**1,219**	**1,452**	**2,597**

Appendix A-2. Distribution of Model Process Heaters Between Fuel Switching Scenarios A, B, and C

Model Parameters (Capacity in MMBtu/hr)						Known		Assumed		Total		
Model No	Material	Combustor Type	Capacity Range	Avg Capacity	Final # of Units	Case A	Case B	Heaters w/o Capacity Data distributed into Model - Case A	Heaters w/o Capacity Data distributed into Model - Case B	Case A	Case B	Case C
1	Coal	Other	0-10	4	0	0	0	0	0	0	0	0
2	Coal	Other	10-100	54	0	0	0	0	0	0	0	0
3	Coal	Other	100-250	166	0	0	0	0	0	0	0	0
4	Coal	Other	>250	565	0	0	0	0	0	0	0	0
5	Coal	Wall-fired/PC	0-10	2	0	0	0	0	0	0	0	0
6	Coal	Wall-fired/PC	10-100	57	0	0	0	0	0	0	0	0
7	Coal	Wall-fired/PC	100-250	186	0	0	0	0	0	0	0	0
8	Coal	Wall-fired/PC	>250	600	0	0	0	0	0	0	0	0
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0	0	0	0	0	0	0	0
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	0	0	0	0	0	0	0
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	0	0	0	0	0	0	0
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	0	0	0	0	0	0	0	0
40	Residual Liquid FF	All	0-10	3	75	2	4	9	17	11	21	43
41	Residual Liquid FF	All	10-100	37	516	36	44	97	118	133	162	221
42	Residual Liquid FF	All	100-250	172	66	5	30	2	10	7	40	20
43	Residual Liquid FF	All	>250	547	17	0	9	0	3	0	12	5
47	Coal	Other	0-10	4	0	0	0	0	0	0	0	0
48	Coal	Other	10-100	54	0	0	0	0	0	0	0	0
49	Coal	Other	100-250	466	0	0	0	0	0	0	0	0
50	Coal	Other	>250	565	0	0	0	0	0	0	0	0
52	Coal	Wall-fired/PC	10-100	57	0	0	0	0	0	0	0	0
53	Coal	Wall-fired/PC	100-250	186	0	0	0	0	0	0	0	0
54	Coal	Wall-fired/PC	>250	600	0	0	0	0	0	0	0	0
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0	0	0	0	0	0	0	0
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	0	0	0	0	0	0	0
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	0	0	0	0	0	0	0
80	Residual Liquid FF	All	0-10	3	8	1	1	3	3	4	4	0
81	Residual Liquid FF	All	10-100	37	23	9	1	12	1	21	2	0
82	Residual Liquid FF	All	100-250	172	0	0	0	0	0	0	0	0
83	Residual Liquid FF	All	>250	547	0	0	0	0	0	0	0	0
	TOTAL				**705**	**53**	**89**	**122**	**152**	**175**	**241**	**289**

Appendix A-3. Fuel Switching Costing Algorithsm

Total Capital Investment $TCI_{fs} = (293)\ (CF_{fs})(HI)$ Case / Description / CF_{fs} A — Gas @ combustion unit — 8.74 B — Gas @ plant — 12.63 C — No gas: $TCI_{case\ C} = TCI_{case\ B} + (C_{pipe})(pipe)(\%_{case})$ $TCI_{case\ c} = TCI_{case\ c1} + TCI_{case\ c2} + TCI_{case\ c3} + TCI_{case\ c4}$	TCI_{fs} = total capital investment of fuel switching, $ CF_{fs} = cost factor for fuel switching, $/kw, see Appendix A-6 HI = heat input, MMBtu/hr C_{pipe} = cost factor for piping, $/foot pipe pipe = piping distance, feet TCI_{case} = capital invt for case C1, C2, C3, C4 $TCI_{case\ c}$ = capital investment for case C $\%_{case}$ = percent of units in case
Total Annual Cost $TAC = delF + EL + CR + All_{SO2} + CAP$	delF = difference in fuel cost $/yr EL = efficiency loss, $/yr CR = capital recovery, $/yr All_{SO2} = SO2 allowance, $/yr CAP = capacity recovery, $/yr
$delF = (CF_g - CF_{corr})(HI)\ (0)$	CF_g = cost factor for gas, $/MMBtu CF_{corr} = cost factor for coal or resd., $/MMBtu HI = heat input, MMBtu/hr 0 = hours of operation
$EL = \left[\frac{HI}{1 - ELF} - HI\right][\theta][CF_g]$	EL = efficiency loss, $/yr HI = heat input, MMBtu/hr 0 = hours of operation ELF = efficiency loss factor CF_g = cost factor for gas, $MMBtu
$CR = (TC1)(CRF_{fs})$	CRF_{fs} = capital recovery factor fuel switching
$CFR_{fs} = \frac{[i\ (1+i)^n]}{[(1+i)^n - 1]}$	i = interest rate, fraction n = life of equipment, yrs

Appendix A-4. Fuel Switching Input Parameters and Values

Parameter	Description	Value	Unit
CF-A, coal	Cost factor for scenario A, coal	8.74	$/kw
CF-B, coal	Cost factor for scenario B, coal	12.63	$/kw
CF-A, oil	Cost factor for scenario A, oil	6.05	$/kw
CF-B, oil	Cost factor for scenario B, oil	9.91	$/kw
CF-C1	Cost factor for case C1	125	$/foot pipe
CF-C2	Cost factor for case C2	25	$/foot pipe
CF-C3	Cost factor for case C3	25	$/foot pipe
Cost-gas	Cost of gas per volume	3.59	$/Mscf
HV-gas	Heating value of gas	1,020	Btu/scf
CFg	Cost of gas per MMBtu	3.52	$/MMBtu
Cost-coal	Cost of coal per mass	35.72	$/metric ton
HV-coal	Heating value of coal	12,000	Btu/lb
CFc	Cost of coal per MMBtu	1.35	$/MMBtu
Cfdo	Cost factor for distillate oil	5.10	$/MMBtu
Cfro	Cost factor for residual oil	2.90	$/MMBtu
i	Interest rate	0.07	%
n	Life of equipment	20	years
CRF	Capital recovery factor	0.09439293	
ELF	Efficiency loss	0.05	
theta	Hours of operation a year	8,400	hours/year

Capital Cost Components	System		Scenario[a]		Cost Breakdowns ($/kw) for Each Site[b]				
	Gas system	Boiler system	A	B	Boiler 1 (Table 9)[c]	Boiler 2 (Table 10)[c]	Boiler 3 (Table 11)[c]	Boiler 4 (Table 12)[c]	Boiler 5 (Table 13)[c]
Electrical gas meter house	x			x			0.6		
Regulator house extension	x			x		0.13			
Mechanical erection pkg	x			x		2.9			
Insulation	x					0.62	0.6		
Platforms and supports	x			x		0.17			
Gas house extension	x			x	0.5				
Conduit and Cable	x			x	2	0.16			
Gas piping	x						4.8		4.04
Gas,vent purge piping	x				3.2				
U.G. Piping and tap	x			x			0.3		
Grating and pipe supports	x			x	0.3				
Meters, regulators, and scrubber	x			x			2.6		
Purging	x			x		0.01			
Electrical boiler		x	x	x		1.5	2		0.28
Fans, ducts, temp. probes		x	x	x		0.1			
Mechanical fabrication pkg		x	x	x		0.72			0.24
Superheater upgrading		x	x	x		2.31			
Gas ignition control system		x	x	x	3.5				
Boiler controls		x	x	x					
Boiler modifications		x	x	x	3.2		2.1		4.04
Burner managment system ctrol vlv		x	x	x					
Fans		x	x	x					
Valves, instruments, controls		x	x	x	3		0.4		
Ignitor modifications		x	x	x		0.57			
Administrative			x	x					
Design			x	x					
Engineering			x	x					0.5
Overhead			x	x					0.2
Project Management			x	x	0.5	0.95	0.5		
Test, start-up, calibration			x	x		0.21	0.1		
Training			x	x					
Transportation			x	x		0.01			
Vendor representative			x	x	0.1	0.88	0.5		
Building and excavation							0.5		

a Scenario A = Boiler already has gas as a startup or backup
Scenario B = Plant uses gas as a fuel but boiler does not

b Data taken from Reference 8.

c Data for each boiler was taken from the noted Table in Reference 8

Appendix A-6. Fuel Switching--Components of Capital Cost for Each Natural Gas Scenario

Scenario A

Capital Cost Components	System		Cost Breakdowns ($/kw) for Each Site[a]						
	Gas system	Boiler system	Boiler 1 (Table 9)[b]	Boiler 2 (Table 10)[b]	Boiler 3 (Table 11)[b]	Boiler 4 (Table 12)[b]	Boiler 5 (Table 13)[b]	Average Cost	Average Cost (in 1997 Dollars)
Electrical boiler		x		1.5	2		0.28		
Superheater upgrading		x		2.31					
Gas ignition control system		x	3.5						
Boiler controls		x							
Boiler modifications		x	3.2		2.1		4.04		
Burner managment system		x							
Valves, instruments, controls		x	3		0.4				
Ignitor modifications		x		0.57					
Fans, ducts, temp. probes		x		0.1					
Mechanical fabrication pkg		x		0.72			0.24		
Purging	x			0.01					
Subtotal			**9.7**	**5.21**	**4.5**		**4.56**	**5.99**	**7.24**
Administrative									
Design									
Engineering							0.5		
Overhead							0.2		
Project Management			0.5	0.95	0.5				
Test, start-up, calibration				0.21	0.1				
Training									
Transportation				0.01					
Vendor representative			0.1	0.88	0.5				
Building and excavation					0.5				
Subtotal			**0.6**	**2.05**	**1.6**		**0.7**	**1.24**	**1.50**
Total								**7.23**	**8.74**

Scenario B

Capital Cost Components	System		Cost Breakdowns ($/kw) for Each Site[a]						
	Gas system	Boiler system	Boiler 1 (Table 9)[b]	Boiler 2 (Table 10)[b]	Boiler 3 (Table 11)[b]	Boiler 4 (Table 12)[b]	Boiler 5 (Table 13)[b]	Average Cost	Average Cost (in 1997 Dollars)
Electrical gas meter house	x				0.6				
Regulator house extension	x			0.13					
Mechanical erection pkg	x			2.9					
Platforms and supports	x			0.17					
Gas house extension	x		0.5						
Conduit and Cable	x		2	0.16					
U.G. Piping and tap	x				0.3				
Grating and pipe supports	x		0.3						
Meters, regulators, and scrubber	x				2.6				
Purging	x			0.01					
Subtotal			**2.8**	**3.37**	**3.5**			**3.22**	**3.90**
Electrical boiler		x		1.5	2		0.28		
Fans, ducts, temp probes		x		0.1					
Mechanical fabrication pkg		x		0.72			0.24		
Superheater upgrading		x		2.31					
Gas ignition control system		x	3.5						
Boiler controls		x							
Boiler modifications		x	3.2		2.1		4.04		
Burner managment system		x							
Fans		x							
Valves, instruments, controls		x	3		0.4				
Ignitor modifications		x		0.57					
Subtotal			**9.7**	**5.2**	**4.5**		**4.56**	**5.99**	**7.24**
Administrative									
Design									
Engineering							0.5		
Overhead							0.2		
Project Management			0.5	0.95	0.5				
Test, start-up, calibration				0.21	0.1				
Training									
Transportation				0.01					
Vendor representative			0.1	0.88	0.5				
Building and excavation					0.5				
Subtotal			**0.6**	**2.05**	**1.6**		**0.7**	**1.24**	**1.50**
Total								**10.45**	**12.63**

a Data taken from reference 8

b Data for each boiler was taken from the noted Table in Reference 8

Appendix A-7. Summary of Fuel Switching Costs for All Boilers and Process Heaters Assigned to Each Applicable Model Unit

Model No	Material	Combustor Type	Capacity Range (MMBtu/hr)	No. of Boilers	No. of Heaters	Total Capital Investment ($)			Total Annual Costs ($/yr)		
						Boiler Fuel Switching	Heater Fuel Switching	Total Fuel Switching	Boiler Fuel Switching	Heater Fuel Switching	Total Fuel Switching
1	Coal	Other	0-10	83	0	17,216,016	0	17,216,016	8,216,675	0	8,216,675
2	Coal	Other	10-100	919	0	262,258,854	0	262,258,854	1,003,403,469	0	1,003,403,469
3	Coal	Other	100-250	509	0	336,553,198	0	336,553,198	1,697,833,339	0	1,697,833,339
4	Coal	Other	>250	204	0	422,992,860	0	422,992,860	2,306,934,969	0	2,306,934,969
5	Coal	Wall-fired/PC	0-10	12	0	1,277,558	0	1,277,558	598,902	0	598,902
6	Coal	Wall-fired/PC	10-100	98	0	23,237,489	0	23,237,489	112,456,085	0	112,456,085
7	Coal	Wall-fired/PC	100-250	212	0	146,998,419	0	146,998,419	791,860,501	0	791,860,501
8	Coal	Wall-fired/PC	>250	291	0	591,571,540	0	591,571,540	3,498,591,792	0	3,498,591,792
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	7	0	1,604,483	0	1,604,483	978,885	0	978,885
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	67	0	22,034,050	0	22,034,050	48,134,768	0	48,134,768
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	18	0	11,716,403	0	11,716,403	62,572,304	0	62,572,304
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	77	0	146,345,808	0	146,345,808	871,679,071	0	871,679,071
40	Residual Liquid FF	All	0-10	477	75	89,908,618	11,400,818	101,309,435	18,207,874	5,515,993	23,723,867
41	Residual Liquid FF	All	10-100	1,154	516	321,616,111	120,083,824	441,699,935	317,534,242	387,544,277	705,078,519
42	Residual Liquid FF	All	100-250	264	66	145,060,286	45,653,139	190,713,425	319,682,287	228,243,474	547,925,761
43	Residual Liquid FF	All	>250	141	17	210,390,295	35,621,095	246,011,389	539,554,206	186,781,423	726,335,629
47	Coal	Other	0-10	36	0	9,389,755	0	9,389,755	1,839,340	0	1,839,340
48	Coal	Other	10-100	70	0	15,002,895	0	15,002,895	26,915,780	0	26,915,780
49	Coal	Other	100-250	29	0	39,839,259	0	39,839,259	94,862,605	0	94,862,605
50	Coal	Other	>250	7	0	10,085,356	0	10,085,356	27,567,428	0	27,567,428
52	Coal	Wall-fired/PC	10-100	32	0	6,135,600	0	6,135,600	12,897,842	0	12,897,842
53	Coal	Wall-fired/PC	100-250	9	0	7,077,388	0	7,077,388	11,873,271	0	11,873,271
54	Coal	Wall-fired/PC	>250	15	0	18,715,031	0	18,715,031	62,518,961	0	62,518,961
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	1	0	276,475	0	276,475	65,029	0	65,029
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	2	0	698,486	0	698,486	534,196	0	534,196
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	1	0	748,155	0	748,155	1,228,670	0	1,228,670
80	Residual Liquid FF	All	0-10	159	8	18,601,502	75,137	18,676,639	4,957,869	481,913	5,439,782
81	Residual Liquid FF	All	10-100	304	23	42,545,168	2,276,252	44,821,420	79,895,059	17,051,225	96,946,284
82	Residual Liquid FF	All	100-250	63	0	33,227,462	0	33,227,462	76,183,650	0	76,183,650
83	Residual Liquid FF	All	>250	7	0	6,787,477	0	6,787,477	26,540,852	0	26,540,852
	TOTAL			**5,268**	**705**	**2,959,911,994**	**215,110,265**	**3,175,022,259**	**12,026,119,921**	**825,618,306**	**12,851,738,227**

Appendix A-8. Capital Investment and Annual Cost for All Boilers in Applicable Models for Fuel Switching

Model Parameters						Total Number			Capital Investment for Each Scenario				Total Annual Cost					
Model No.	Material	Combustor Type	Capacity Range (MMBtu/hr)	Average Capacity (MMBtu/hr)	No. of Units	Case A	Case B	Case C	Case A	Case B	Case C	Total	Additional Fuel Cost	Efficiency Loss	Capital Recovery - Case A	Capital Recovery - Case B	Capital Recovery - Case C	Total
1	Coal	Other	0-10	4	83	5	13	64	54,851	198,161	16,963,004	17,216,016	6,004,844	512,662	5,178	18,705	1,675,287	8,216,675
2	Coal	Other	10-100	54	919	192	361	366	26,513,772	72,225,081	163,520,001	262,258,854	900,981,751	76,921,071	2,502,713	6,817,537	16,180,397	1,003,403,469
3	Coal	Other	100-250	166	509	114	210	185	48,281,785	129,205,641	159,065,772	336,553,198	1,534,556,062	131,012,305	4,557,459	12,196,098	15,511,414	1,697,833,339
4	Coal	Other	>250	565	204	50	32	122	72,343,165	66,906,667	283,743,028	422,992,860	2,088,394,720	178,296,129	6,828,683	6,315,516	27,099,921	2,306,934,969
5	Coal	Wall-fired/PC	0-10	2	12	2	5	5	12,292	35,526	1,229,740	1,277,558	435,722	37,200	1,160	3,353	121,467	598,902
6	Coal	Wall-fired/PC	10-100	57	98	58	14	26	8,514,727	2,953,071	11,769,692	23,237,489	101,554,932	8,670,225	803,730	278,749	1,148,449	112,456,085
7	Coal	Wall-fired/PC	100-250	186	212	68	82	63	32,179,883	56,123,717	58,694,818	146,998,419	716,633,892	61,182,423	3,037,553	5,297,682	5,708,950	791,860,501
8	Coal	Wall-fired/PC	>250	600	291	114	76	100	175,915,740	169,474,889	246,180,912	591,571,540	3,171,652,278	270,778,948	16,605,201	15,997,231	23,558,135	3,498,591,792
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	7	0	1	6	0	25,904	1,578,579	1,604,483	759,196	64,816	0	2,445	152,427	978,885
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	67	8	4	55	727,894	525,932	20,780,224	22,034,050	42,394,931	3,619,456	68,708	49,644	2,002,029	48,134,768
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	18	4	10	4	1,876,328	6,100,749	3,739,326	11,716,403	56,628,434	4,834,637	177,112	575,868	356,253	62,572,304
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	77	32	20	26	46,048,836	40,785,189	59,511,783	146,345,808	790,365,776	67,477,262	4,346,684	3,849,833	5,639,515	871,679,071
40	Residual Liquid FF	All	0-10	3	477	48	82	347	256,877	710,048	88,941,693	89,908,618	7,398,404	2,210,729	24,247	67,023	8,507,471	18,207,874
41	Residual Liquid FF	All	10-100	37	1,154	129	210	815	8,485,270	22,516,401	290,614,441	321,616,111	220,800,625	65,977,776	800,949	2,125,389	27,829,503	317,534,242
42	Residual Liquid FF	All	100-250	172	264	71	85	108	21,697,976	42,420,671	80,941,639	145,060,286	235,518,361	70,375,605	2,048,135	4,004,211	7,735,974	319,682,287
43	Residual Liquid FF	All	>250	547	141	44	39	58	42,584,662	62,411,813	105,393,820	210,390,295	400,031,197	119,533,940	4,019,691	5,891,234	10,078,145	539,554,206
47	Coal	Other	0-10	4	36	0	0	36	0	0	9,389,755	9,389,755	742,452	221,853	0	0	875,034	1,839,340
48	Coal	Other	10-100	54	70	5	48	18	478,616	7,447,811	7,076,468	15,002,895	19,637,024	5,867,770	45,178	703,021	662,787	26,915,780
49	Coal	Other	100-250	466	29	3	16	10	2,661,732	21,799,809	15,377,718	39,839,259	70,146,309	20,960,527	251,249	2,057,748	1,446,773	94,862,605
50	Coal	Other	>250	565	7	4	0	4	3,505,415	0	6,579,940	10,085,356	20,494,652	6,124,039	330,886	0	617,851	27,567,428
52	Coal	Wall-fired/PC	10-100	57	32	5	23	5	461,902	3,783,015	1,890,683	6,135,600	9,485,821	2,834,473	43,600	357,090	176,858	12,897,842
53	Coal	Wall-fired/PC	100-250	186	9	0	0	9	0	0	7,077,388	7,077,388	8,631,010	2,579,045	0	0	663,216	11,873,271
54	Coal	Wall-fired/PC	>250	600	15	12	0	3	12,763,080	0	5,951,951	18,715,031	46,778,256	13,977,883	1,204,744	0	558,078	62,518,961
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	1	0	0	1	0	0	276,475	276,475	30,936	9,244	0	0	24,849	65,029
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	2	0	0	2	0	0	698,486	698,486	360,914	107,845	0	0	65,436	534,196
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	1	0	0	1	0	0	748,155	748,155	891,974	266,532	0	0	70,163	1,228,670
80	Residual Liquid FF	All	0-10	3	159	42	47	70	223,823	407,362	17,970,316	18,601,502	2,473,256	739,038	21,127	38,452	1,685,995	4,957,869
81	Residual Liquid FF	All	10-100	37	304	184	49	71	12,084,101	5,278,389	25,182,678	42,545,168	58,443,490	17,463,590	1,140,654	498,243	2,349,083	79,895,059
82	Residual Liquid FF	All	100-250	172	63	17	27	20	5,054,851	13,247,888	14,924,722	33,227,462	56,255,676	16,809,845	477,142	1,250,507	1,390,480	76,183,650
83	Residual Liquid FF	All	>250	547	7	7	0	0	6,787,477	0	0	6,787,477	19,941,432	5,958,730	640,690	0	0	26,540,852
TOTAL					**5,268**	**1,219**	**1,452**	**2,597**	**529,515,055**	**724,583,734**	**1,705,813,206**	**2,959,911,994**	**10,588,424,330**	**1,155,425,598**	**49,982,475**	**68,395,579**	**163,891,940**	**12,026,119,921**

Appendix A-9. Capital Investment and Annual Cost for All Process Heaters in Applicable Models for Fuel Switching

Model Parameters						Total Number			Capital Investment				Annual Cost					
Model No.	Material	Combustor Type	Capacity Range (MMBtu/hr)	Average Capacity (MMBtu/hr)	No. of Units	Case A	Case B	Case C	Case A	Case B	Case C	Total	Additional Fuel Cost	Efficiency Loss	Capital Recovery - Case A	Capital Recovery - Case B	Capital Recovery - Case C	Total
1	Coal	Other	0-10	4	0	--	--	--	--	--	--	--	--	--	--	--	--	--
2	Coal	Other	10-100	54	0	--	--	--	--	--	--	--	--	--	--	--	--	--
3	Coal	Other	100-250	166	0	--	--	--	--	--	--	--	--	--	--	--	--	--
4	Coal	Other	>250	565	0	--	--	--	--	--	--	--	--	--	--	--	--	--
5	Coal	Wall-fired/PC	0-10	2	0	--	--	--	--	--	--	--	--	--	--	--	--	--
6	Coal	Wall-fired/PC	10-100	57	0	--	--	--	--	--	--	--	--	--	--	--	--	--
7	Coal	Wall-fired/PC	100-250	186	0	--	--	--	--	--	--	--	--	--	--	--	--	--
8	Coal	Wall-fired/PC	>250	600	0	--	--	--	--	--	--	--	--	--	--	--	--	--
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0	--	--	--	--	--	--	--	--	--	--	--	--	--
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	--	--	--	--	--	--	--	--	--	--	--	--	--
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	--	--	--	--	--	--	--	--	--	--	--	--	--
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	0	--	--	--	--	--	--	--	--	--	--	--	--	--
40	Residual Liquid FF	All	0-10	3	75	11	21	43	82,312	237,895	11,080,611	11,400,818	4,077,864	348,147	7,770	22,456	1,059,757	5,515,993
41	Residual Liquid FF	All	10-100	37	516	133	162	221	12,572,017	22,204,809	85,306,999	120,083,824	346,517,509	29,583,838	1,186,709	2,095,977	8,160,244	387,544,277
42	Residual Liquid FF	All	100-250	172	66	7	40	20	2,907,043	25,205,459	17,540,638	45,653,139	206,303,483	17,613,104	274,404	2,379,217	1,673,266	228,243,474
43	Residual Liquid FF	All	>250	547	17	0	12	5	0	23,823,544	11,797,550	35,621,095	168,980,627	14,426,675	0	2,248,774	1,125,347	186,781,423
47	Coal	Other	0-10	4	0	--	--	--	--	--	--	--	--	--	--	--	--	--
48	Coal	Other	10-100	54	0	--	--	--	--	--	--	--	--	--	--	--	--	--
49	Coal	Other	100-250	466	0	--	--	--	--	--	--	--	--	--	--	--	--	--
50	Coal	Other	>250	565	0	--	--	--	--	--	--	--	--	--	--	--	--	--
52	Coal	Wall-fired/PC	10-100	57	0	--	--	--	--	--	--	--	--	--	--	--	--	--
53	Coal	Wall-fired/PC	100-250	186	0	--	--	--	--	--	--	--	--	--	--	--	--	--
54	Coal	Wall-fired/PC	>250	600	0	--	--	--	--	--	--	--	--	--	--	--	--	--
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0	--	--	--	--	--	--	--	--	--	--	--	--	--
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	--	--	--	--	--	--	--	--	--	--	--	--	--
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	--	--	--	--	--	--	--	--	--	--	--	--	--
80	Residual Liquid FF	All	0-10	3	8	4	4	0	30,730	44,407	0	75,137	437,472	37,349	2,901	4,192	0	481,913
81	Residual Liquid FF	All	10-100	37	23	21	2	0	1,961,332	314,920	0	2,276,252	15,512,028	1,324,335	185,136	29,726	0	17,051,225
82	Residual Liquid FF	All	100-250	172	0	--	--	--	--	--	--	--	--	--	--	--	--	--
83	Residual Liquid FF	All	>250	547	0	--	--	--	--	--	--	--	--	--	--	--	--	--
--	**TOTAL**				**705**	**175**	**241**	**289**	**17,553,433**	**71,831,034**	**125,725,797**	**215,110,265**	**741,828,983**	**63,333,447**	**1,656,920**	**6,780,341**	**12,018,614**	**825,618,306**

Appendix A-10. Breakdown of Case C Costs for Boilers

Model Parameters						Number of Case C Boilers					Capital Cost					
					% population	5	84	10	1	62 500 00	132 000	1 320 000	< = $ per unit		$/model
Model No.	Material	Combustor Type	Capacity Range (MMBtu/hr)	Average Capacity (MMBtu/hr)	No. of Units	Total	C1 (500 feet)	C2 (1 mile)	C3 (10 miles)	C4 (No Pipe)	C1 (500 feet)	C2 (1 mile)	C3 (10 miles)	avg C4 (No Pipe)	C4 (No Pipe) - Add on Control	Total
1	Coal	Other	0-10	4	83	64	3	54	6	1	200 806	7 124 934	8 482 065	332 315	211 539	16 021 345
2	Coal	Other	10-100	54	919	366	18	307	37	4	1,143 240	40 563 999	48 290 475	313 657	1 147 472	91 145,186
3	Coal	Other	100-250	166	509	185	9	155	19	2	578,409	20,522 880	24 432,000	523 272	968 528	46,501,817
4	Coal	Other	>250	565	204	122	6	102	12	1	381,250	13 527,360	16,104 000	983,251	1 199 566	31,212,176
5	Coal	Wall fired/PC	0-10	2	12	5	0	4	0	0	15,000	532,224	633,600	286 369	13 746	1 194,570
6	Coal	Wall fired/PC	10-100	57	98	26	1	22	3	0	80,208	2 845 920	3 388 000	373 014	95 740	6,409,868
7	Coal	Wall fired/PC	100-250	186	212	63	3	53	6	1	196,566	6,974 474	8 302 945	569,702	358 349	15 832,333
8	Coal	Wall fired/PC	>250	600	291	100	5	84	10	1	313,064	11 107 995	13 223 803	1,322,232	1 324 616	25,969,478
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	7	6	0	5	1	0	18,229	646,800	770 000	262 698	15 324	1,450,353
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	67	55	3	46	5	1	171,307	6,078 240	7 236,000	484 496	265 592	13,751,139
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	18	4	0	4	0	0	13,235	469 609	559 059	309,138	13 093	1 054,996
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	77	26	1	22	3	0	80,208	2,845,920	3,388 000	271,088	69 579	6 383,708
40	Residual Liquid FF	All	0-10	3	477	347	17	292	35	3	1,084,949	38 495 711	45 828,228	155,183	538 770	85,947,658
41	Residual Liquid FF	All	10-100	37	1,154	815	41	685	82	8	2,547,015	90,372,172	107 585 919	419,755	3 421 191	203,926 298
42	Residual Liquid FF	All	100-250	172	264	108	5	91	11	1	337,174	11,963,470	14 242 226	974,932	1 051 909	27,594,779
43	Residual Liquid FF	All	>250	547	141	58	3	49	6	1	180,584	6,407,410	7 627,869	542 856	313 700	14 529,562
47	Coal	Other	0-10	4	36	36	2	30	4	0 4	112,500	3,991 680	4 752,000	332 315	119 634	8,975,814
48	Coal	Other	10-100	54	70	18	1	15	2	0 2	54,688	1,940,400	2 310,000	313 657	54 890	4,359,977
49	Coal	Other	100-250	466	29	10	0 5	8	1	0 1	30,208	1,071,840	1,276,000	523 272	50 583	2 428,631
50	Coal	Other	>250	565	7	4	0 2	3	0 4	0 04	10,938	388,080	462 000	983 251	34 414	895,431
52	Coal	Wall fired/PC	10-100	57	32	5	0 2	4	0 5	0 05	14 286	506,880	603,429	373 014	17 052	1,141,646
53	Coal	Wall fired/PC	100-250	186	9	9	0 5	8	1	0 1	28,125	997,920	1,188 000	569 702	51 273	2,265,318
54	Coal	Wall fired/PC	>250	600	15	3	0 2	3	0 3	0 03	9,375	332,640	396 000	1,322,232	39 667	777,682
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	1	1	0 1	1	0 1	0 01	3,125	110 880	132,000	1,322,232	13 222	259,227
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	2	2	0 1	2	0 2	0 02	6 250	221,760	264 000	262,698	5 254	497,264
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	1	1	0 1	1	0 1	0 01	3,125	110 880	132 000	484 496	4 845	250,850
80	Residual Liquid FF	All	0-10	3	159	70	4	59	7	1	219,210	7,777,906	9 259 412	155,183	108 856	17,365,384
81	Residual Liquid FF	All	10-100	37	304	71	4	59	7	1	220,707	7,831,040	9 322 667	419 755	296 457	17,670,871
82	Residual Liquid FF	All	100-250	172	63	20	1	17	2	0 2	62,171	2,205 928	2 628 105	974,932	193 960	5,088,165
83	Residual Liquid FF	All	>250	547	7	0	0	0	0	0	0	0	0	0	0	0
	TOTAL				6,268	2,587	130	2,182	260	26	8,115,952	287,966,953	342,817,801	16,160,693	12,000,821	650,901,527

Appendix A-11. Breakdown of Case C Costs for Process Heaters

Model Parameters						Case C Boilers					Capital Cost				
						% population	5	84	10	1	62 500	132,000	1 320,000	< = $ per unit	$/model
Model No.	Material	Combustor Type	Capacity Range (MMBtu/hr)	Average Capacity (MMBtu/hr)	No. of Units	Total	C1 (500 feet)	C2 (1 mile)	C3 (10 miles)	C4(No Pipe)	C1 (500 feet)	C2 (1 mile)	C3 (10 miles)	C4 (No Pipe) Add on control	Total
1	Coal	Other	0-10	4	0	--	--	--	--	--	--	--	--	--	--
2	Coal	Other	10-100	54	0	--	--	--	--	--	--	--	--	--	--
3	Coal	Other	100-250	166	0	--	--	--	--	--	--	--	--	--	--
4	Coal	Other	>250	565	0	--	--	--	--	--	--	--	--	--	--
5	Coal	Wall-fired/PC	0-10	2	0	--	--	--	--	--	--	--	--	--	--
6	Coal	Wall-fired/PC	10-100	57	0	--	--	--	--	--	--	--	--	--	--
7	Coal	Wall-fired/PC	100-250	186	0	--	--	--	--	--	--	--	--	--	--
8	Coal	Wall-fired/PC	>250	600	0	--	--	--	--	--	--	--	--	--	--
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0	--	--	--	--	--	--	--	--	--	--
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	--	--	--	--	--	--	--	--	--	--
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	--	--	--	--	--	--	--	--	--	--
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	0	--	--	--	--	--	--	--	--	--	--
40	Residual Liquid FF	All	0-10	3	75	43	2	36	4	0	133,929	4,752,000	5,657,143	66,507	10,609,578
41	Residual Liquid FF	All	10-100	37	516	221	11	186	22	2	691,071	24,520,320	29,190,857	928,258	55,330,507
42	Residual Liquid FF	All	100-250	172	66	20	1	17	2	0	61,875	2,195,424	2,613,600	193,037	5,063,936
43	Residual Liquid FF	All	>250	547	17	5	0	4	1	0	16,346	579,988	690,462	28,396	1,315,191
47	Coal	Other	0-10	4	0	--	--	--	--	--	--	--	--	--	--
48	Coal	Other	10-100	54	0	--	--	--	--	--	--	--	--	--	--
49	Coal	Other	100-250	466	0	--	--	--	--	--	--	--	--	--	--
50	Coal	Other	>250	565	0	--	--	--	--	--	--	--	--	--	--
52	Coal	Wall-fired/PC	10-100	57	0	--	--	--	--	--	--	--	--	--	--
53	Coal	Wall-fired/PC	100-250	186	0	--	--	--	--	--	--	--	--	--	--
54	Coal	Wall-fired/PC	>250	600	0	--	--	--	--	--	--	--	--	--	--
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0	--	--	--	--	--	--	--	--	--	--
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	--	--	--	--	--	--	--	--	--	--
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	--	--	--	--	--	--	--	--	--	--
80	Residual Liquid FF	All	0-10	3	8	0	0	0	0	0	0	0	0	0	0
81	Residual Liquid FF	All	10-100	37	23	0	0	0	0	0	0	0	0	0	0
82	Residual Liquid FF	All	100-250	172	0	0	0	0	0	0	0	0	0	0	0
83	Residual Liquid FF	All	>250	547	0	0	0	0	0	0	0	0	0	0	0
	TOTAL				**705**	**289**	**14**	**243**	**29**	**3**	**903,221**	**32,047,732**	**38,152,062**	**1,216,197**	**72,319,212**

Attachment A-12. Comparison of Fuel Switching Costs to Add-on Control Costs

Model No	Material	Combustor Type	Capacity Range (MMBtu/hr)	Avg. Capacity (MMBtu/hr)	No. of Boilers	No. of Heaters	Total Capital Investment ($)		Total Annual Costs ($/yr)	
							Total Floor Controls	Total Fuel Switching	Total Floor Controls	Total Fuel Switching
1	Coal	Other	0-10	4	83	0	0	17,216,016	0	8,216,675
2	Coal	Other	10-100	54	919	0	219,124,058	262,258,854	198,377,984	1,003,403,469
3	Coal	Other	100-250	166	509	0	232,912,814	336,553,198	156,043,348	1,697,833,339
4	Coal	Other	>250	565	204	0	196,436,023	422,992,860	76,962,031	2,306,934,969
5	Coal	Wall-fired/PC	0-10	2	12	0	0	1,277,558	0	598,902
6	Coal	Wall-fired/PC	10-100	57	98	0	26,917,402	23,237,489	16,467,757	112,456,085
7	Coal	Wall-fired/PC	100-250	186	212	0	108,958,207	146,998,419	67,304,974	791,860,501
8	Coal	Wall-fired/PC	>250	600	291	0	382,606,184	591,571,540	139,169,534	3,498,591,792
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	7	0	0	1,604,483	0	978,885
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	67	0	31,676,062	22,034,050	6,662,316	48,134,768
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	18	0	2,301,915	11,716,403	1,598,081	62,572,304
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	77	0	16,910,191	146,345,808	6,767,664	871,679,071
40	Residual Liquid FF	All	0-10	3	477	75	0	101,309,435	0	23,723,867
41	Residual Liquid FF	All	10-100	37	1,154	516	0	441,699,935	0	705,078,519
42	Residual Liquid FF	All	100-250	172	264	66	0	190,713,425	0	547,925,761
43	Residual Liquid FF	All	>250	547	141	17	0	246,011,389	0	726,335,629
47	Coal	Other	0-10	4	36	0	7,623,718	9,389,755	1,852,194	1,839,340
48	Coal	Other	10-100	54	70	0	30,850,366	15,002,895	7,046,840	26,915,780
49	Coal	Other	100-250	466	29	0	28,960,511	39,839,259	5,252,701	94,862,605
50	Coal	Other	>250	565	7	0	56,000	10,085,356	56,000	27,567,428
52	Coal	Wall-fired/PC	10-100	57	32	0	15,807,877	6,135,600	4,009,020	12,897,842
53	Coal	Wall-fired/PC	100-250	186	9	0	7,333,746	7,077,388	1,367,661	11,873,271
54	Coal	Wall-fired/PC	>250	600	15	0	120,000	18,715,031	120,000	62,518,961
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	1	0	123,231	276,475	38,165	65,029
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	2	0	585,663	698,486	131,893	534,196
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	1	0	8,000	748,155	8,000	1,228,670
80	Residual Liquid FF	All	0-10	3	159	8	0	18,676,639	0	5,439,782
81	Residual Liquid FF	All	10-100	37	304	23	0	44,821,420	0	96,946,284
82	Residual Liquid FF	All	100-250	172	63	0	0	33,227,462	0	76,183,650
83	Residual Liquid FF	All	>250	547	7	0	0	6,787,477	0	26,540,852
TOTAL					**5,268**	**705**	**1,309,311,968**	**3,175,022,259**	**689,236,164**	**12,851,738,227**

Appendix A-13. Fuel Switching Emission Reductions For Each Boiler Model.

Model Parameters						Selected HAPs										
Model No	Material	Combustor Type	Capacity Range (MMBtu/hr)	Average Capacity (MMBtu/hr)	No of Boilers	Acetaldehyde	Arsenic	Benzene	Chromium	Formaldehyde	Hydrochloric Acid	Hydrofluoric Acid	Lead	Manganese	Mercury	Toluene
1	Coal	Other	0-10	4	83											
2	Coal	Other	10-100	54	919	-27 82	15 17	1 27	16 53	-29 89	5952 73	400 99	21 32	90 34	0 62	1.74
3	Coal	Other	100-250	167	509	-47 44	18 56	2 13	20 16	-50 93	9979 92	638.47	26 08	110 57	1 05	2 91
4	Coal	Other	>250	565	204	-64 98	15 49	2 80	16 70	-69 62	11311 67	718 25	21 74	92 34	1 43	3 82
5	Coal	Wall-fired/PC	0-10	2	12											
6	Coal	Wall-fired/PC	10-100	57	98	-3 14	0 91	0 14	0 99	-3 37	613 86	38 51	1 28	5 45	0 07	0 19
7	Coal	Wall-fired/PC	100-250	186	212	-22 18	4 10	0 98	4 39	-23 79	4398.88	265 34	5 75	24 44	0 49	1 33
8	Coal	Wall-fired/PC	>250	600	291	-97 93	12 85	4 45	13 65	-105 18	19074 27	1225 14	18 02	76 77	2 17	6 07
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	7											
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	67	8 59	0 28	20 87	0 64	21 08	71 34	72 01	0 76	4 53	0 01	0.00
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	18	12 05	0 14	29 42	0 32	29 66	94 28	86 00	0 38	2 30	0 01	0 00
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	77	180 63	1 25	442 45	2 71	445 38	1211 09	1103 48	3 36	20 27	0 19	0 00
40	Residual Liquid FF	All	0-10	3	477											
41	Residual Liquid FF	All	10-100	37	1154	-25 07	0 49	0 76	2 82	-19 91	5 59	0 00	1 49	130 58	0 86	3 55
42	Residual Liquid FF	All	100-250	172	264	-26 66	0 49	0 81	2 81	-21 18	5 73	0 00	1 49	130 68	0 91	3 77
43	Residual Liquid FF	All	>250	547	141	-45.26	0 88	1.38	5 08	-35 89	10.33	0 00	2 69	235 35	1 55	6 44
47	Coal	Other	0-10	4	36											
48	Coal	Other	10-100	54	70	-0 35	0 25	0 02	0 28	-0 38	77.10	5.51	0 36	1 52	0 01	0.02
49	Coal	Other	100-250	167	29	-0 45	0 31	0 02	0 34	-0 48	98 19	7 07	0 44	1 87	0 01	0 03
50	Coal	Other	>250	565	7	-0.37	0 03	0 02	0 03	-0 40	80 67	4 95	0.04	0 19	0.01	0.02
52	Coal	Wall-fired/PC	10-100	57	32	-0 17	0 13	0.01	0 14	-0 18	32 84	2 39	0 18	0 78	0 00	0 01
53	Coal	Wall-fired/PC	100-250	186	9	-0 16	0 08	0.01	0 09	-0 17	34 14	2 40	0 12	0 50	0 00	0.01
54	Coal	Wall-fired/PC	>250	600	15	-0 84	0 07	0 04	0 07	-0 90	183.57	12 02	0 10	0 43	0.02	0.05
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	1											
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	2	0 04	0.00	0 09	0.00	0 09	0 30	0.31	0 00	0 02	0.00	0 00
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	1	0 08	0 00	0 20	0 00	0 20	0 75	0 54	0 00	0 01	0 00	0 00
80	Residual Liquid FF	All	0-10	3	159											
81	Residual Liquid FF	All	10-100	37	304	-1 10	0 02	0 03	0 13	-0 87	0 24	0 00	0 07	5 90	0 04	0 16
82	Residual Liquid FF	All	100-250	172	63	-1 06	0.02	0 03	0 12	-0 84	0 24	0.00	0 07	5 74	0.04	0.15
83	Residual Liquid FF	All	>250	547	7	-0 37	0.01	0.01	0 04	-0 30	0 09	0.00	0 02	2 03	0 01	0.05

Appendix A-14. Fuel Switching Emission Reductions For Each Process Heater Model.

Model Parameters						Selected HAPs										
Model No	Material	Combustor Type	Capacity Range (MMBtu/hr)	Average Capacity (MMBtu/hr)	No of Heaters	Acetaldehyde	Arsenic	Benzene	Chromium	Formaldehyde	Hydrochloric Acid	Hydrofluoric Acid	Lead	Manganese	Mercury	Toluene
1	Coal	Other	0-10	4	0											
2	Coal	Other	10-100	54	0	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
3	Coal	Other	100-250	167	0	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
4	Coal	Other	>250	565	0	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
5	Coal	Wall-fired/PC	0-10	2	0											
6	Coal	Wall-fired/PC	10-100	57	0	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
7	Coal	Wall-fired/PC	100-250	186	0	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
8	Coal	Wall-fired/PC	>250	600	0	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
9	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0											
10	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
11	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
12	Coal/Wood/NFF Liquid/NFF Solid	All	>250	565	0	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
40	Residual Liquid FF	All	0-10	3	75											
41	Residual Liquid FF	All	10-100	37	516	-11 20	0 22	0 34	1 30	-8 89	2 54	0 00	0 69	60 10	0 38	1 59
42	Residual Liquid FF	All	100-250	172	66	-6 66	0 13	0 20	0.78	-5.28	1 52	0 00	0 41	36 07	0 23	0 95
43	Residual Liquid FF	All	>250	547	17	-5.46	0.11	0 17	0 64	-4.33	1 25	0 00	0 34	29 55	0 19	0 78
47	Coal	Other	0-10	4	0											
48	Coal	Other	10-100	54	0	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
49	Coal	Other	100-250	167	0	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
50	Coal	Other	>250	565	0	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00
52	Coal	Wall-fired/PC	10-100	57	0	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00
53	Coal	Wall-fired/PC	100-250	186	0	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
54	Coal	Wall-fired/PC	>250	600	0	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
55	Coal/Wood/NFF Liquid/NFF Solid	All	0-10	6	0											
56	Coal/Wood/NFF Liquid/NFF Solid	All	10-100	35	0	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
57	Coal/Wood/NFF Liquid/NFF Solid	All	100-250	173	0	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
80	Residual Liquid FF	All	0-10	3	8											
81	Residual Liquid FF	All	10-100	37	23	-0 08	0 00	0 00	0 01	-0 07	0 02	0 00	0 01	0 45	0.00	0 01
82	Residual Liquid FF	All	100-250	172	0	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
83	Residual Liquid FF	All	>250	547	0	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00

Appendix A-15. Comparison of Emission Reductions From Fuel Switching vs. Add-on MACT Controls

		Metals										Acid Gases				Organics							
		Arsenic		Chromium		Lead		Manganese		Mercury		Hydrogen Chloride		Hydrogen Fluoride		Acetaldehyde		Benzene		Formaldehyde		Toluene	
Combustor	Fuel	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT	Fuel Switch	MACT
Boiler	Coal	70	48	77	54	100	69	432	297	6 1	1 5	53,216	37 036	4,583	2,400	64	0	505	0	211	0	16	0
	Residual	2	0	11	0	5 8	0	510	0	3 4	0	22	0	0	0	100	0	3 0	0	-79	0	14	0
	Total	72	48	88	54	106	69	943	297	9 5	1 5	53,238	37 036	4,583	2,400	164	0	508	0	132	0	30	0
Process Heaters	Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Residual	0 5	0	2 7	0	1 4	0	126	0	0 8	0	5 3	0	0	0	23	0	0 7	0	-19	0	3 3	0
	Total	0 5	0	2 7	0	1 4	0	126	0	0.8	0	5 3	0	0	0	23	0	0 7	0	-19	0	3 3	0
Total	Coal	70	48	77	54	100	69	432	297	6 1	1 5	53,216	37,036	4,583	2,400	64	0	505	0	211	0	16	0
	Residual	2 5	0	14	0	7 2	0	636	0	4 2	0	27	0	0	0	123	0	3 7	0	-98	0	17	0
	Total	73	48	91	54	107	69	1,069	297	10	1 5	53,243	37,036	4,583	2,400	187	0	509	0	113	0	33	0